Dynamic Response Analysis of Highway Embankment with Different Fill Material Modifications

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Abstract -**Safety and stability analysis of civil structures have become one of the most important research areas in Geotechnical Earthquake Engineering. This has become imperative due to the increasing stability failures of foundations and embankment slopes as a result of the occurrence of unexpected ground shakes. In this research the dynamic response analysis of highway embankment under different ground modifications was carried out using 2D FEM CAD based software (Geo-Studio) to run numerical model of the highway embankment. The main objective of the present research is to determine the maximum and minimum permanent displacements at the crest, middle and near toe part of the highway embankment body that is subjected to the peak acceleration of an earthquake record. A conceptual model was made of the highway embankment configuration and the engineering properties of the materials modelled are by far large estimates which were refined by data reported by various researchers. Mohr-Coulomb linear elastic model was used for the embankment materials in establishing the initial static stress-strain conditions. The Equivalent elastic constitutive model was used to establish the stress-strain relationship in the dynamic model. Different scenarios of embankment fill modifications were considered. These included normal fill embankment, normal fill embankment with geogrid reinforcement, fly ash fill embankment, fly ash fill embankment with geogrid reinforcement. The maximum vertical and horizontal displacements occur at the crest of the embankment in all three cases of fill material modifications. The maximum vertical displacement of 22cm was observed in normal fill embankment followed by 17.9cm in normal + fly ash fill embankment. In the normal fill geogrid reinforced embankment, 6.8cm of vertical displacement was observed. The least vertical displacement of 5cm was observed in normal + fly ash fill with geogrid reinforced embankment. The fly ash fill with geogrid reinforced embankment prove to be the best performer in seismically active zones.**

Keywords - Dynamic Analysis, Seismic Stability, Earthquake, Numerical Modelling, HighwayEmbankment.

I. INTRODUCTION

Highway embankments in seismically active zones need to be evaluated to make sure they can withstand earthquakes while protecting public safety, life and property. Earthquake occurrence induces significant inertia forces in embankment slopes and worst of all, these induced forces are cyclic in nature and change directions alternatively several times during the short period of the motion. Earthquakes impose additional loads on embankment dams over those experienced under static conditions.

Embankment Slope failures occur when the overall permanent displacements caused by the motion exceeds certain safe limits. The behaviour of embankments and dams and their foundations under earthquake loading is extremely complex problem that is still being explored extensively as an engineering discipline. Factors such as the embankment characterization, site conditions and earthquake loading specifications that highly affect the dynamic response of the embankment and the non-linear behaviour of the soil materials often makes the prediction of the response ofembankment during an earthquake a major challenge to design engineers.

Progress in geotechnical computations and the falling cost of computer programmes offer interesting facilities such as the development of constitutive models for numerical analysis ofembankment and dam response in considering complex issues as the soil behaviour, the generation of pore-water pressure, embankment construction procedure and the simulation of real earthquake records.

For the past decades, most existing dams and embankments were design against earthquakes using the pseudo-static approach proposed by Terzaghi [1]in which the effect of the earthquake is represented by constant horizontal and/or vertical accelerations and the earthquake effect on a potential soil mass is represented by means of equivalent static horizontal force equal to the soil mass multiplied by a seismic coefficient.

Slope instability in highway embankments commonly occur as soil settlement or sliding due to inadequate or loss of shear strength in the fill material. The choice and suitability of embankment fill material contributes significantly to the stability and reduction in cost of constructing embankments on soft grounds.Flyash as a waste material generated from Thermal plants in India is being used as fill material. Coupled with geogrids, they are observed to creditably improve the shear strength of soft soils [2].

This study presents numerical study of the seismic behaviour of highway embankment on soft soil. The analysis is conducted using GEOSTUDIO 2004 to represent the response of the embankment in undrained conditions. The behaviour of the fill materials and foundation materials of the embankment is described by “equivalent-linear” elastic model. The “equivalent-linear” elastic model is common in earthquake engineering for modelling wave transmission in layered sites and dynamic soil-structure interaction [3].

II. MODEL DESCRIPTION

The embankment section assumed in this study is a symmetric zone section of a typical highway embankment with crest width of 8.5m and 2:1 side slopes. The height of the embankment is 4m and resting on soft clay layer beneath which is a well graded sand both assumed to be fully saturated. The embankment is constructed on the soft soil in two lifts each with a height of 2m. A pavement layer of 0.3m with strength properties presented in Table 3 was modelled.

The finite element model was generated using Quake/W of GEOSTUDIO 2004 geotechnical software. Though the focus is on the earthquake response, Sigma/W and Slope/W were utilised to analyse the initial stress and slope stability respectively. Owing to the symmetry of the embankment configuration, only one half is modelled. 15 nodes and 294 plain-strain elements were adopted to discretise both the embankment and foundation materials.

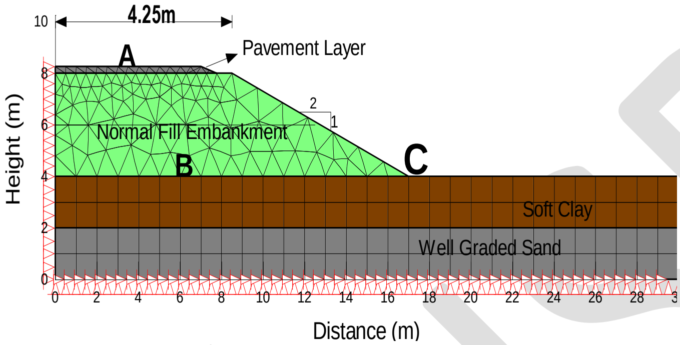


Fig. 1 Model configuration with imposed boundary conditions.

III. NUMERICAL ANALYSIS

Three different scenarios of fill material modifications of the embankment were simulated and the results are presented in the subsequent sections. These include normal and fly ash fill embankment, normal fill with geogrid reinforced embankment and normal and fly ash fill with geogrid reinforced embankment.

A. *Initial Conditions*

The Sigma/W initial analysis type was conducted to establish the total static stress distribution throughout the embankment in each of the fill material modifications. To compute the static stress, it is necessary to specify the Poisson's ratio and the unit weight of both embankment and foundation materials. The initial state slope stability was also analysed and the results presented. Mohr-Coulomb linear elastic model was used to achieve these in both cases. Table 1 shows the properties of the fill materials for simulating the initial conditions.The highway traffic loading was simulated with a uniformly distributed load of 100kPa placed over the pavement.

Table 1 Properties of Embankment Fill Materials

Soil	ɣ (kN/m^3)	Φ (^{0})	C (kPa)
Well Graded Sand	20	34	10
Soft Clay	18	24	20
Normal Fill	20	30	15
Fly Ash	15.27	31	16.7

Table 2 Properties of Geogrid

Ultimate Strength	100kN/m
Allowable Capacity	50kN/m
Fibre Thickness	0.3cm
Bond Safety Factor	2
Interaction Coefficient	0.6

Table 3 Strength Properties of Pavement Material

Property	EA (kN/m)	EI (kNm^2/m)	ɣ (kN/m^3)	η
Concrete	1.58E11	1.179E9	24	0.15

EA = Axial Stiffness *EI = Bending Stiffness*
η = Damping Ratio

B. *Dynamic Analysis*

The purpose of the dynamic analysis is to determine the excess pore-pressures that may develop and the permanent displacements that may occur at selected points inside the embankment. The Equivalent Linear Dynamic analysis type is used here with an impervious boundary condition adopted as shown in Figure 6. In QUAKE/W, selected points can be flagged where the results will be saved for each and every time step while integrating through the earthquake record which is defined as History Nodes. Three History Nodes marked as A, B and C have been specified in the model as shown in Figure 6.

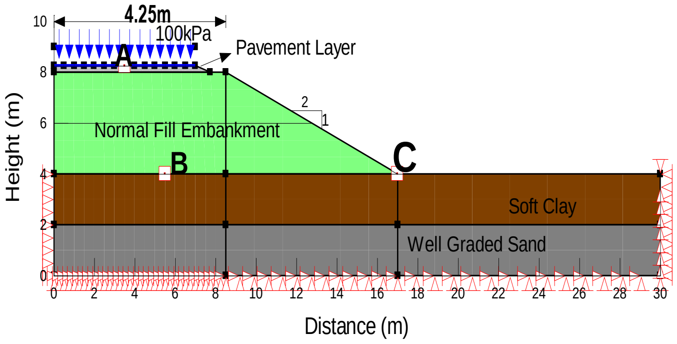


Fig. 6 History Nodes A, B and C.

The embankment was subjected to a time-history of an earthquake record as shown in Figure 7. The peak ground acceleration was set at 0.15g over a duration of 10 seconds. The input dynamic properties are as presented in Table 4.

Table 4 Geotechnical Properties for Dynamic Analysis

Soil	E	G	ν	η
	(MPa)	*(MPa)*		
Well Graded Sand	30	11.5	0.3	0.12
Soft Clay	1	0.38	0.38	0.085
Fill Material	3	1.15	0.3	0.11
Fly ash	2.2	0.88	0.25	0.10

E = Young modulus G = Shear modulus
ν = Poisson's ratio η = Damping ratio

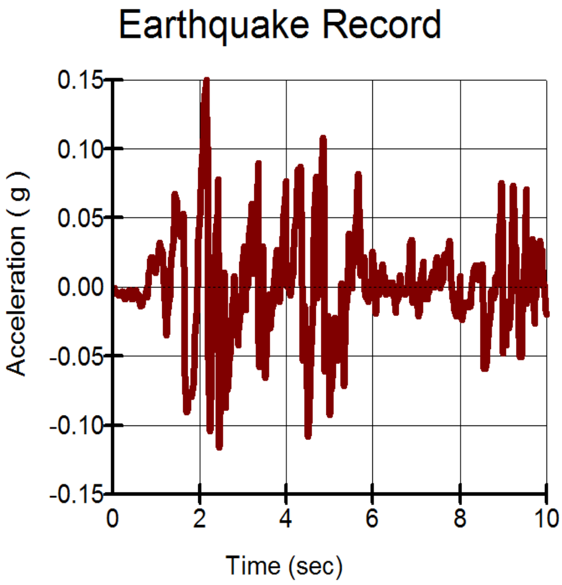


Fig. 7Earthquake Time-History record.

IV. RESULTS AND DISCUSSIONS

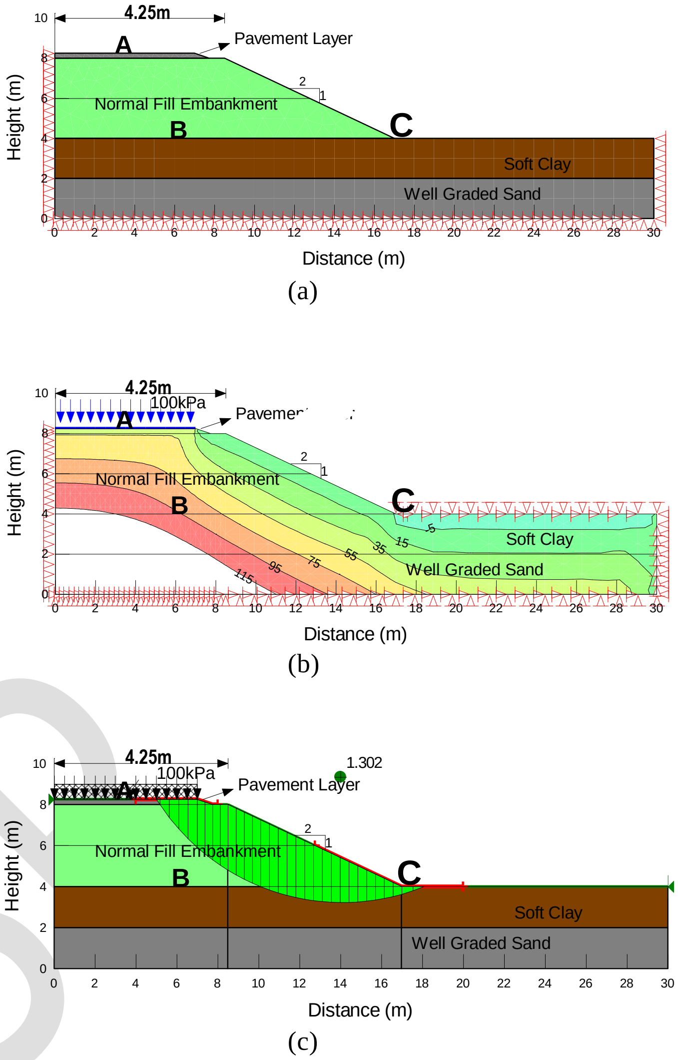
A. Initial Vertical Stress

The total stress distributionsfor each scenario are shown by the stress contours in Figs. 2b-5b. It can be observed that more stress concentration occurs at bottom of the normal fill as the loads are transmitted from the top to the bottom. The intensity of stress is reduced from 115kPa to 95kPa when fly ash layers are used in between the normal fill due to its low unit weight and high strength properties.

From Figs. 3b and 5b, it is observed that stresses are found to be decreasing and outwardly distributed towards the edges of the embankment with the use of different embankment fill materials. The least stress is observed in the normal soil reinforced with geogrid.

B. Pre-quake Slope Stability

The static condition stability factors are shown in Figs. 2c, 3c, 4c and 5c. It is observed that the fly ash – geogrid reinforced combination prove to be better performer than the geogrid and normal fill alone embankment. As mentioned earlier, the stress is reduced significantly whereas the overall strength of the embankment is increased leading to a higher stability of the embankment.

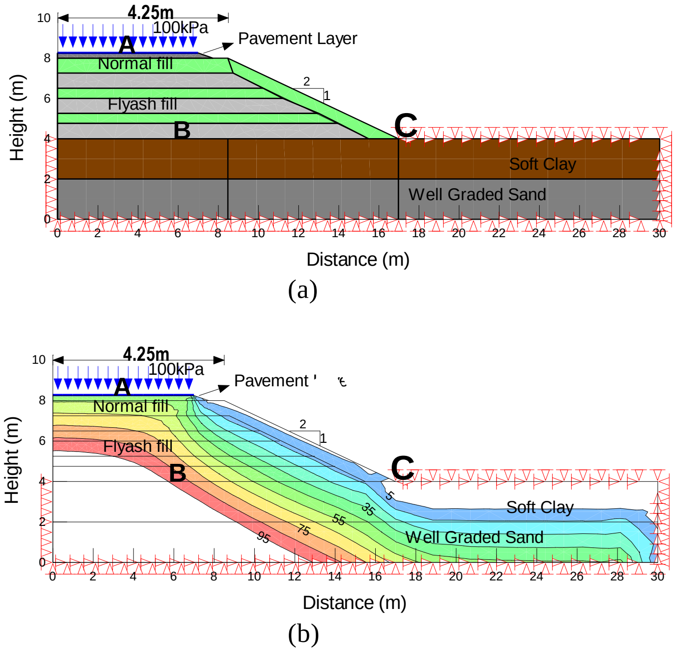


(a)

(b)

(c)

Fig. 2 (a) Normal fill Embankment (b) Initial Vertical Stress Condition (c) Static Slope Stability.



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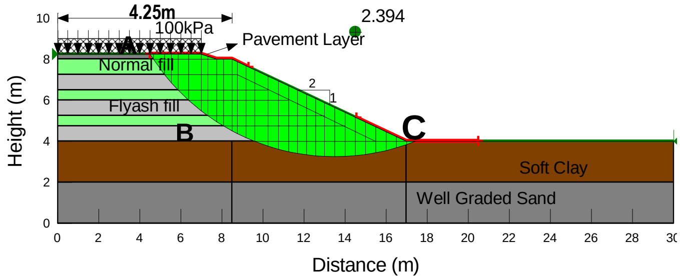
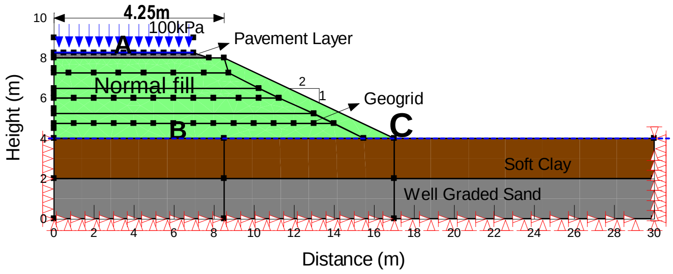


(c)

Fig. 3 (a) Fly Ash Fill Embankment (b) Initial Vertical Stress Condition (c) Static Slope Stability.



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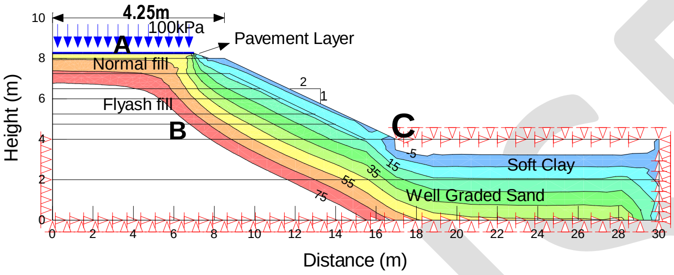

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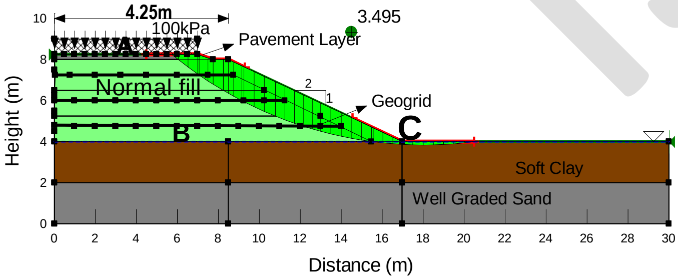

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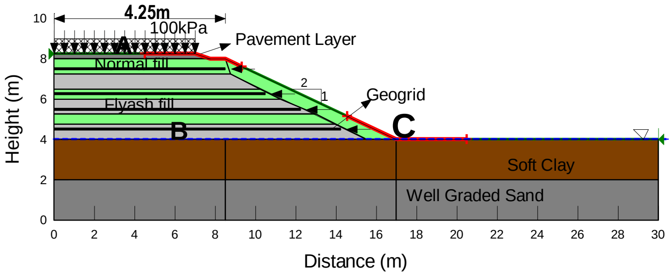
Fig. 4(a) Normal fill + Geogrid Reinforced Embankment (b) Initial Vertical Stress Condition (c) Static Slope Stability.



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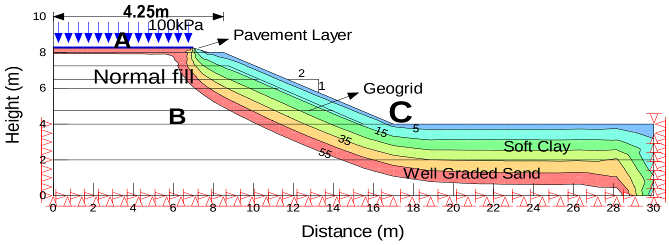

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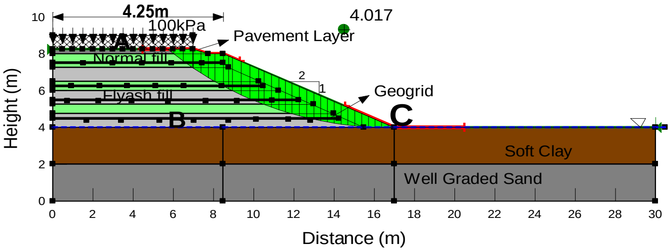
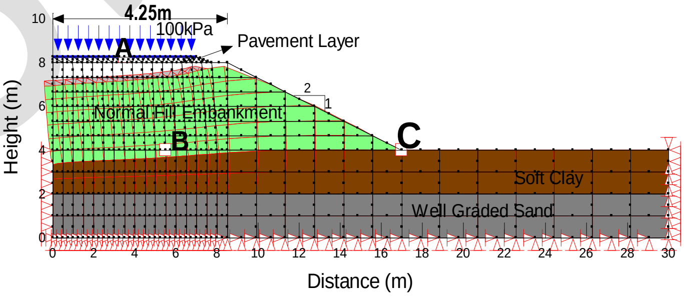


(c)

Fig. 5(a) Normal + Fly Ash Fill + Geogrid Reinforced Embankment (b) Initial Vertical Stress Condition (c) Static Slope Stability.

In the dynamic analysis, the integration along the earthquake record was set at an interval of 0.02 seconds. A total of 500 integration steps are presented for the 10 second shaking and the results were saved for every 10th time step resulting in 50 sets of output files for the analysis.

The resulting deformed embankment for each of the fill material scenarios are presented below.



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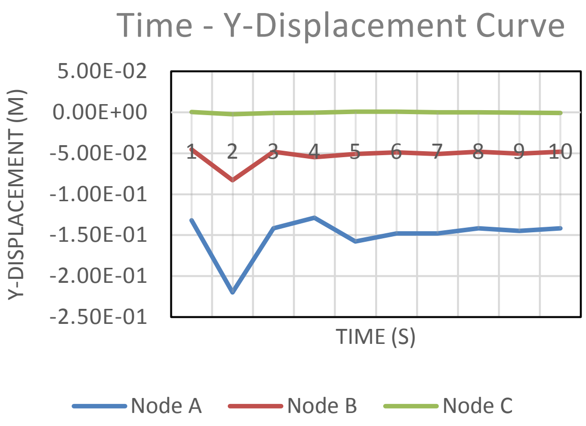

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Fig. 8(a) Deformed Normal Fill Embankment (b) Vertical Displacement at History Nodes

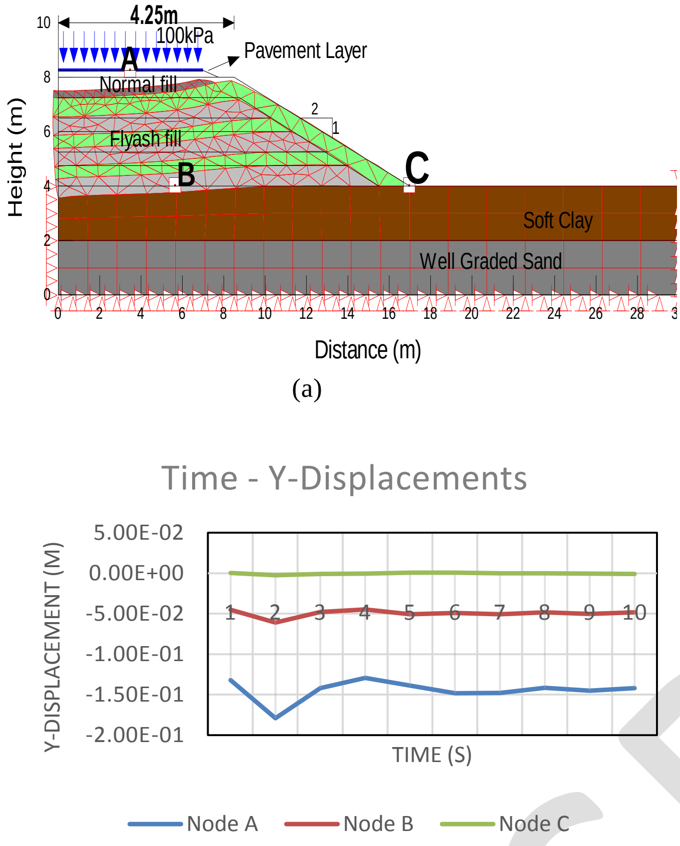

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Fig. 9 (a) Deformed Normal+Flyash Fill Embankment (b) Vertical Displacements at History Nodes.

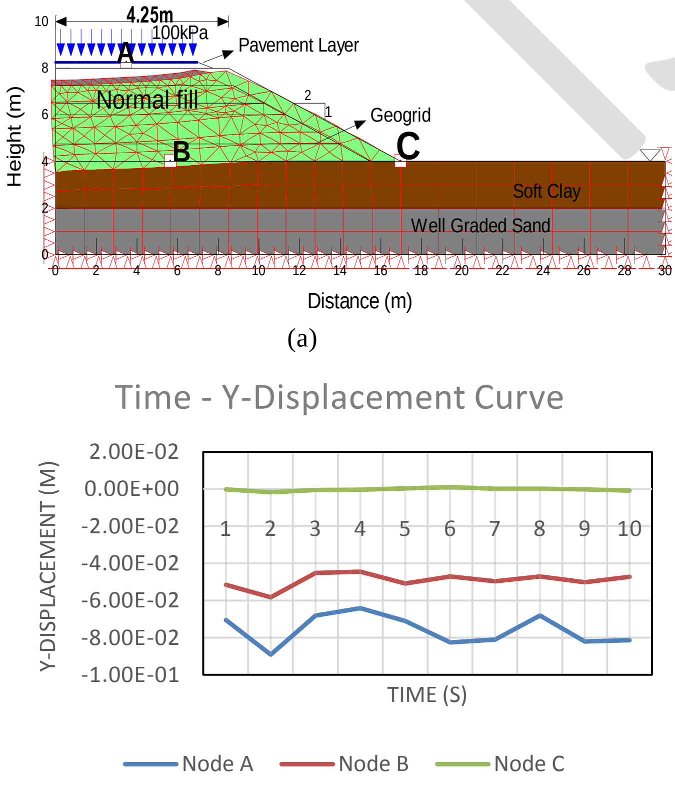

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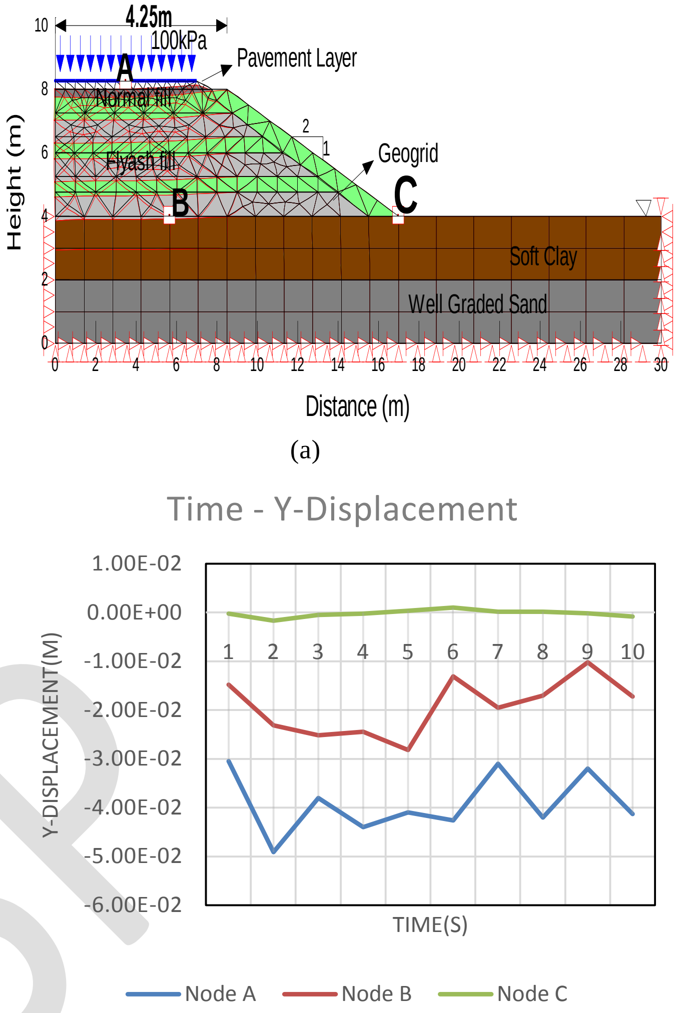
Fig. 10(a) Deformed Normal Fill+Geogrid Reinforced Embankment (b) Vertical Displacements at History Nodes.



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(b)

Fig. 10 Deformed Normal + Flyash Fill + Geogrid Reinforced Embankment.

V. CONCLUSIONS

The maximum vertical and horizontal displacements occur at the crest of the embankment in all three cases of fill material modifications.The maximum vertical displacement of 22cm was observed in normal fill embankment followed by 17.9cm in normal + fly ash fill embankment. In the normal fill geogrid reinforced embankment 6.8cm of vertical displacement was observed. The least vertical displacement of 5cm was observedin normal + fly ash fill with geogrid reinforced embankment. The fly ash fill with geogrid reinforced embankment is the best performer in seismically active zones.

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